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A FLAT-PLATE ANTENNA FOR DBS RECEPTION

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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Summary

A flat-plate antenna for the reception of DBS transmissions using low-cost materials has been designed, built and measured. The antenna is essentially a multilayer printed structure consisting of a polarisation converter, an array of elements and a beamforming network. The antenna can be mounted flat on the most suitable wall of an arbitrarily-orientated house and aligned to receive signals from the satellite.

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A FLAT-PLATE ANTENNA FOR DBS RECEPTION

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1. INTRODUCTION

The introduction of a direct broadcast by satellite (DBS) television service requires suitable receiving antennas to be available. It was originally assumed at the World Administrative Radio Conference of 1977 (WARC-77)[1] that a parabolic dish receiving antenna would be used.

Since WARC-77 the requirements for a DBS receiving antenna have been considered in more detail. It has been shown[2,3] that the antenna requirements depend not only on the broadcast signal power and the desired picture quality, but also the percentage of time for which the service should be available and the location of the receiver in the world. Improvements since 1977 in the performance of low-noise amplifiers have been achieved which allow some reduction in either the receiving antenna size or the broadcast power.

Parabolic dish antennas suffer from a number of disadvantages. They must be mounted rigidly to ensure the required pointing accuracy of a few degrees even in high winds; this can result in a substantial mechanical mount which is both heavy and expensive. Because they must be inclined to the angle of elevation of the satellite, snow and rain can accumulate in the bottom of the dish resulting in loss of antenna gain*. They require a rigid and substantial platform on which, or to which, they are mounted. They can be considered by some people to be environmentally undesirable, especially in very large numbers.

An alternative to the parabolic-dish antenna is the flat-plate antenna. Such an antenna consists of a large number of antenna elements whose outputs are combined together by transmission lines. The individual elements are all mounted in the same plane resulting in a thin, flat structure. The phased-array principle is used to receive signals from the desired direction — which is usually not orthogonal to the plane of the antenna.

In this Report the various advantages that may be gained by using a flat-plate antenna are examined. One of the options is selected and the design, construction and measurement of an antenna to satisfy this requirement is reported.

2. DESIGN PHILOSOPHY

A flat-plate antenna could provide a number of advantages over a parabolic-dish antenna. These are listed below:

(a) the flat-plate antenna could be built with an elevation slew so that it could be mounted vertically,

(b) the antenna could be built with both an elevation and azimuth slew so that it could be mounted flat on the most suitable wall of a house,

(c) the antenna could be built to allow signals from satellites in more than one orbit position to be received.

An ideal antenna would, of course, provide all these options. However as these are realised the design becomes more complicated. This results in an antenna which is likely to be more expensive. Set against this, a domestic flat-plate antenna must be low-cost so that it can compete favourably with a parabolic dish.

The simplest option is a broadside antenna which would be a direct replacement for the parabolic dish[4]. This option would be the easiest to implement but would provide few advantages over the dish. The efficiency of a flat-plate antenna, with the required gain, is unlikely to be any greater than that of a dish so the same area of antenna would be required in each case. The only significant difference would be that the flat-plate antenna would not have a feed protruding outside the plane of the antenna; this may make it more acceptable in the domestic environment and more convenient for retail distribution. These advantages would, of course, apply to all the variants of flat-plate antenna design.

The option with an elevation slew is slightly more complicated. The range of elevation slew angles required for United Kingdom reception is 16° to 29°; to cover this arc, either a range of antennas, each with a different fixed slew angle, or a single antenna with a variable slew angle could be used. Either of them would allow the antenna to be mounted vertically so preventing the loss of gain resulting from the build-up of snow or rain on the face of the antenna, although the antenna could not in most cases be mounted flush on the wall.

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* Some offset feed designs achieve a beam slew which permits the face of the dish to be near vertical.

The option with both an elevation and azimuth slew is considerably more attractive, but is also much more complicated. This option would allow the antenna to be mounted flat on the most favourable wall of a house and so would be much more unobtrusive. In this case, either a means of beam steering or a large number of antenna types with different slew angles would be needed as the azimuth range of angles required is between −45° and +45° (assuming a rectangular house with all walls available). Conventional methods of beam steering over such an angular range use electronic phase shifters which are, at present, too expensive for use in a domestic flat-plate antenna.

A flat-plate antenna could be designed to receive signals from satellites in more than one orbit position. Such an antenna would form two or more beams with the appropriate angular spacings. The antenna would be aligned with the plane of the beams in the plane of the geostationary orbit and would not, in general, lie flat against the wall. However such an antenna would not provide any of the other advantages over a parabolic-dish antenna.

A flat-plate antenna which provided all these options is, in theory, possible; however it would be very complicated and hence an expensive solution. Beam steering over a wide range of angles in two planes would be required. Using conventional techniques this would result in a very expensive antenna.

It was decided to investigate a flat-plate antenna of medium complexity, designed to be mounted flat on the most favourable wall of a rectangular house. To make this solution financially attractive the use of active components to provide beam steering was avoided. A range of antennas each with a different beam slew, would only be acceptable if the number of antennas that would be required in the range was small. The solution was one that allowed the same antenna to be mounted on any house but involved no expensive semiconductor components.

To produce such an antenna a 'polar' method* of beam steering[5] was used. With the 'polar' method the antenna beam is slewed in one plane only and the antenna is mechanically rotated on the wall to achieve the second degree of freedom. For reception in the UK of signals from the orbital position of the UK satellite the range of elevation angles required is 16° to 29°; the range of azimuth angles for an arbitrarily sited house is −45° to +45°. However, it can be shown (Appendix 1) that using the 'polar' method, beam steering is only required in one plane and that the angular range in that plane is reduced to between 16° and 52° on one side of broadside. This range of angles could reasonably be achieved using a range of antennas, each with a different slew angle; however, it would still be preferable to use one antenna which produced the required range of beams. It was therefore decided[6] to use a microwave lens as the beamforming network where the output contour of the lens would consist of either a number of fixed ports or one adjustable port.

3. ANTENNA DESIGN AND CONSTRUCTION

To show that a domestic flat-plate antenna which could be mounted flat on the wall of a building was feasible it was necessary to build a demonstration antenna. It was decided that such an antenna should be designed to receive signals at Kingswood Warren from the French or German DBS satellites which were due to be launched shortly. It should be noted that at the time of the work there were no firm plans for DBS in the UK, but that the launch of these European satellites was imminent. Fortunately, the design requirements for this case do not differ significantly† from those for reception of the UK satellite (when available) throughout the UK. This demonstration antenna should show not only the technical feasibility of the idea but also the financial feasibility, therefore the antenna should be built using low-cost materials and techniques.

The electrical requirements for the antenna can be specified. An antenna boresight gain of around 33 dBi is required to give a carrier-to-noise ratio (C/N) of 14 dB assuming reception in the service area by a reliable receiver. A bandwidth of 400 MHz centred around 11.9 GHz is required to cover the lower half of the DBS band. The antenna should be circularly polarised and have a cross-polar discrimination of at least 20 dB. A range of beam slewing angles of 16° to 52° on one side only of broadside is required. An input impedance match giving a voltage reflection coefficient of better than 40% is required to maintain the antenna efficiency.

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* The 'polar' method of beam steering uses polar co-ordinate variables and is in no way related to polar mounts which are sometimes used for mounting antennas.

† The UK and France are both allocated channels in the same (lower) half of the 12 GHz frequency band, with the same hand of circular polarisation. The French orbit location, 19° W, implies slightly higher elevation angles than for the UK location of 31° W; however, the consequential effects on the range of slew angles needed in the polar method of beam-steering are very small. Provided reception is only required in SE England, i.e. very nearly within the coverage area of the French beam, differences in the G/T requirements may be neglected if a small decrease in the service availability can be accepted. In general, the full degree of protection against interference from other DBS transmissions is not guaranteed for reception outside the service area; however, this is unlikely to be a problem where there are only a few satellites serving the European area. Thus an antenna designed primarily for UK reception of the UK satellite, using the 'polar' method of beam steering, could be demonstrated using the French satellite.

The overall design of the antenna is reduced to solving three, somewhat interactive, problems:

(a) receiving circularly-polarised signals,

(b) achieving sufficient antenna gain and directivity at the desired slew angles,

(c) collecting the signals from each element so as to achieve the desired beam slew with minimum loss in the feed network.

Each of these problems was considered in detail and is discussed in a set of companion Reports[7,8,9]. In this Report the results from each of these references are used to design the flat-plate antenna. In Ref. 8 it is concluded that the most suitable antenna element is a linearly-polarised one which would be used in conjunction with a polarisation converter (or polariser). In Ref. 9 it is concluded that the feed network should take the form of a microwave lens feeding columns of elements, each column of which is fed using a corporate feed network. Each column of elements would thus take the form of a sub-array.

The design of the flat-plate antenna can now be separated into three sections, each of which closely follows the work in one of Refs. 7, 8 or 9:

(a) polariser design,

(b) sub-array design,

(c) microwave lens design.

An exploded view of the antenna is shown in Fig. 1.

To obtain the antenna gain required an array with antenna elements occupying an area 760 mm by 750 mm was designed. This aperture was filled by 50 sub-arrays each comprising 32 elements. The details of the gain calculation and loss budget are given in Appendix 2.

3.1 Polariser design and construction

A polariser is a structure that converts linearly-polarised radiation to circularly-polarised radiation. This is achieved[7] by taking the linearly-polarised radiation which is orientated at 45° to the structure of the polariser and considering it to be resolved into two components in line with and across the structure of the polariser. The structure of the polariser ensures that one component is phase shifted by 90° with respect to the other. The result on the far side of the polariser is circular polarisation. The process is, of course, reciprocal.

Ref. 7 showed that the most suitable polariser for this application was a meander-line polariser. A large meander-line polariser was therefore built using a sandwich of copper-clad polyimide film, which was etched to produce the meander lines, and microwave foam. The overall structure was relatively light, mechanically fairly robust, fairly insensitive to deformation and could be covered by a layer of suitable material to make it waterproof. An exploded view of the polariser is shown in Fig. 2. However, because of the size of the polariser required for the test array it

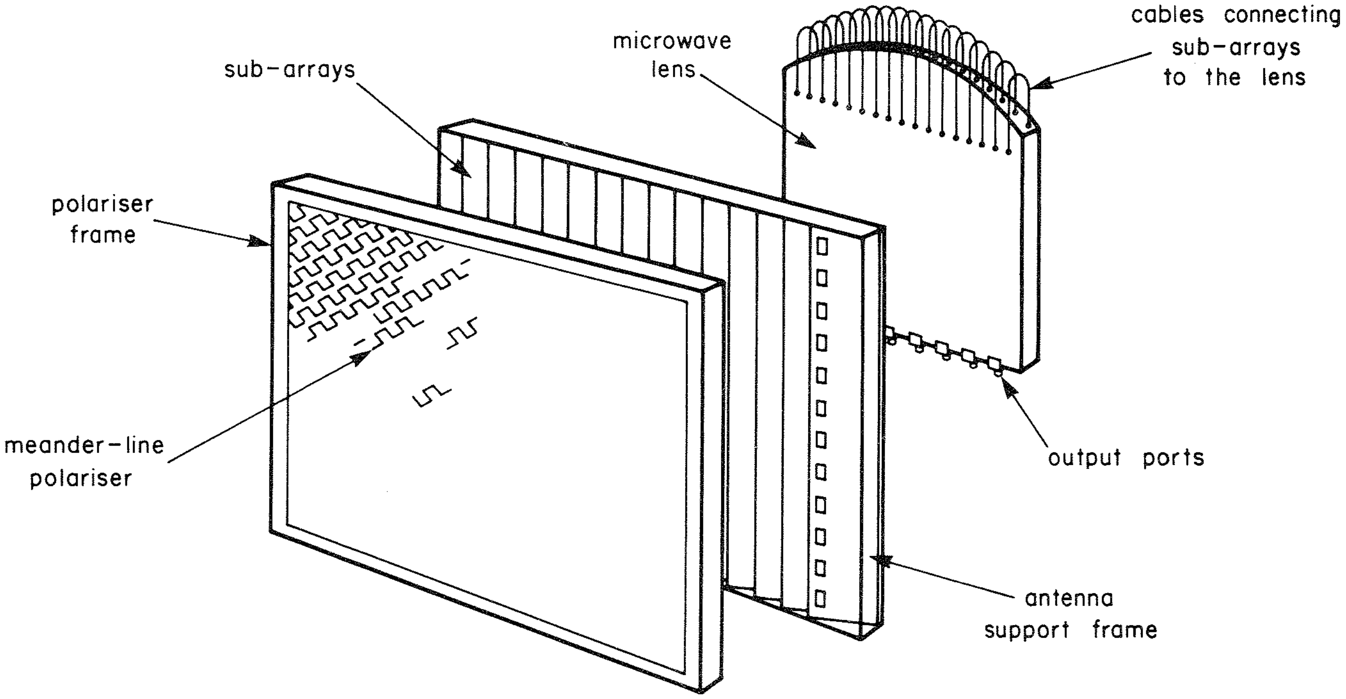

Fig. 1 - Exploded view of the demonstration flat-plane antenna.

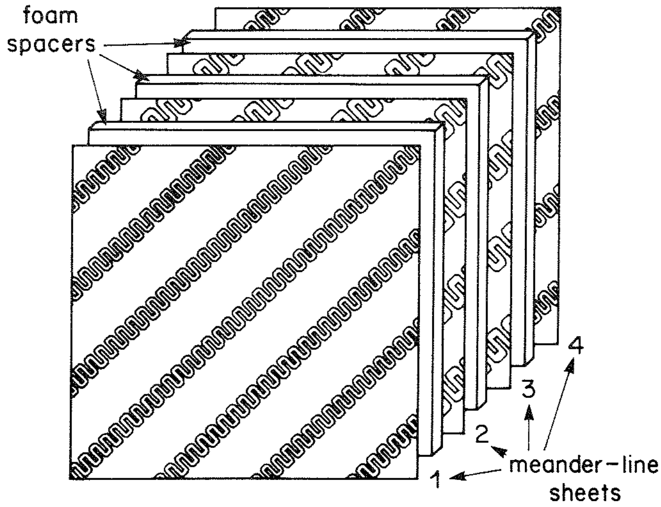

Fig. 2 - Exploded view of the meander-line polariser.

was necessary to make up each meander-line sheet using two strips of etched polyimide film. The lack of electrical continuity along the meander lines may produce a small degradation in performance, but this problem should be overcome in large scale production.

It was expected from results reported in Ref. 7 that this polariser would give an axial ratio of better than 1 dB over the required band. This corresponds to a cross-polar discrimination of around 25 dB. The axial ratio of a polariser when used with an antenna with a slewed beam has not been thoroughly investigated and so the performance of the polariser at the large slew angles required for this application was unknown.

3.2 Sub-array design and construction

The antenna is composed of a number of sub-arrays, each of which is connected to one port of the microwave lens. The sub-arrays are one-dimensional arrays, in that they are 32 antenna elements long but only one element wide. The sub-arrays were designed to have a broadside beam in the plane of the sub-array as the beam steering was done by the microwave lens in the plane across the sub-arrays.

To achieve the desired range of beam-slew angles without producing grating lobes it is necessary to space the elements 0.56 wavelengths apart in the plane of the beam slew. The satisfactory design of an array becomes harder as the elements are spaced closer together because of mutual coupling between the elements. It was decided to relax the element separation and space the elements 15.5 mm apart (corresponding to a spacing of around 0.62 wavelengths). This allows a grating lobe to be formed at the extreme of the beam slew and relies on the radiation pattern of the element to control the level of the lobe. The elements were spaced 24 mm apart (corresponding to a spacing of around 0.95 wavelengths) in the other plane. As no beam slewing occurs in this plane the grating lobes are suppressed.

It was shown in Ref. 9 that a corporate feed network is considerably easier to design than a series feed - particularly in view of the required bandwidth. It was therefore decided to use a corporate feed network to feed the individual elements of the sub-array. The disadvantage of a corporate feed network is that, with a sub-array spacing of 15.5 mm, it cannot be accommodated in a planar structure. A stacking structure was therefore proposed, where the corporate feed for one sub-array lay underneath the elements of the next array. This structure is shown in Fig. 3.

In Ref. 8 various types of antenna element were investigated. The most suitable was found to be a modified folded-dipole patch element based on a structure proposed by Dubost. The element consists of a half-wavelength dipole with two folded arms. The area around the element free from ground plane is small and short-circuit pins were found to be required to suppress spurious modes that would otherwise have been excited. The element, Fig. 4, is fed by capacitative coupling from a triplate feed line. This element was investigated when stacked in the way proposed and the results showed that it still performed satisfactorily. Some increase in the level of the cross-polar component was observed, but the major effect was to slew the element beam slightly in the H-plane. This is a desirable effect as it maintains the element gain in the directions over which the full array will be slewed whilst reducing the level in the directions, on the other side of broadside, which are not required. The mutual coupling between stacked elements was found to be relatively low.

To obtain maximum antenna gain the aperture illumination in the plane of the sub-arrays was chosen to be uniform. The resulting first sidelobe level, at 13 dB below the main beam, was thought to be acceptable. In the other plane the aperture illumination is controlled by the microwave lens and is approximately co-sinusoidal; this should result in a lower sidelobe level.

A number of sub-arrays each consisting of 32 modified folded-dipole patch elements, was constructed. The sub-arrays, Fig. 5, were built using a sandwich of copper-clad polyimide film spaced by microwave foam. The energy from each element was collected together using a triplate corporate feed network. The resulting sandwich was held together using layers of commercially available spray adhesive which was applied through a stencil. This was done to ensure that the elements and feed lines were kept free of glue (the glue increases the transmission line losses). The sub-arrays, like the polariser, were light, relatively

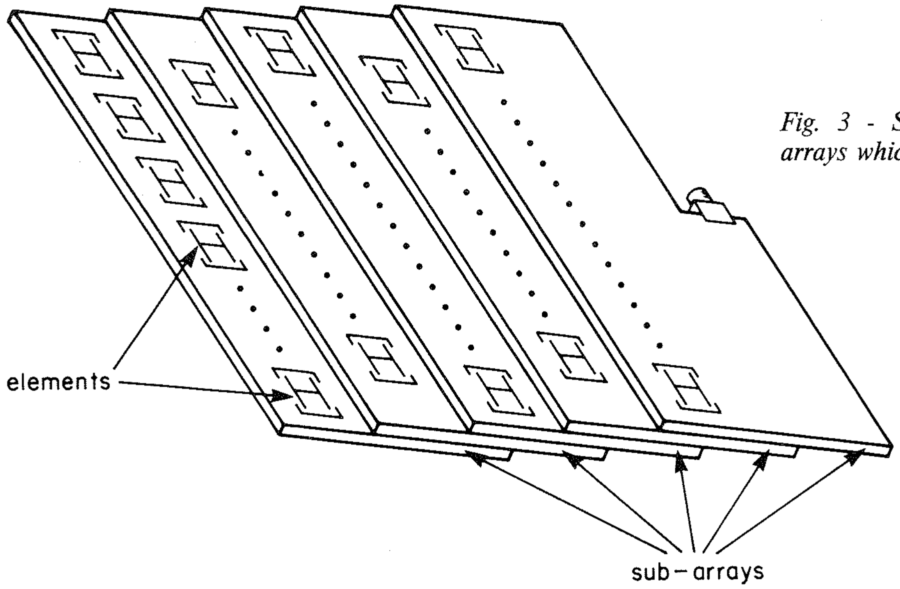

Fig. 3 - Stacking structure for sub-arrays which allows use of a corporate feed network.

robust and used fairly low-cost materials and construction techniques. Each sub-array was expected to give a gain of around 21 dBi over the required range of slew angles.

3.3 Microwave lens design and construction

A microwave lens is a beamforming network which can form one or many beams over a specified angular range. The use of such a lens to provide the necessary range of slewed beams is explained in Section 2. A lens is a reciprocal device and its operation is easier to describe in terms of transmission rather than reception. A signal introduced at one of the input or beam ports, Fig. 6, propagates through the lens cavity and produces a phase taper across the output or array ports. The positions of the array ports are chosen to produce a linear phase taper and hence a slewed beam. The positions of the beam ports are chosen to produce a range of different linear phase

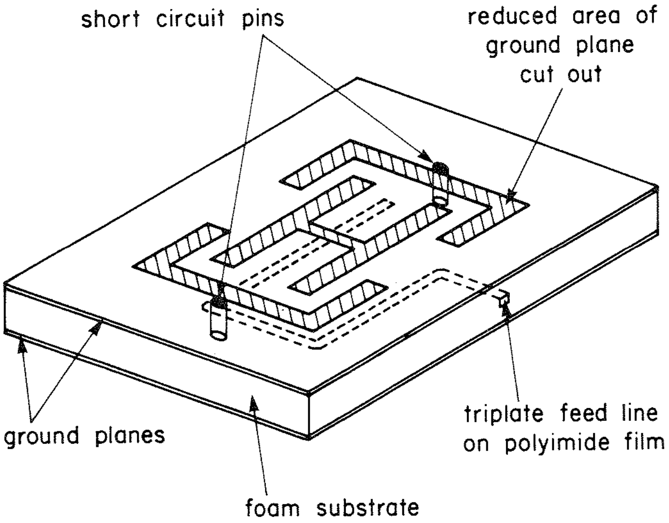
short circuit pins
reduced area of ground plane cut out
ground planes
triplate feed line on polyimide film
foam substrate

Fig. 4 - Modified folded-dipole patch element.

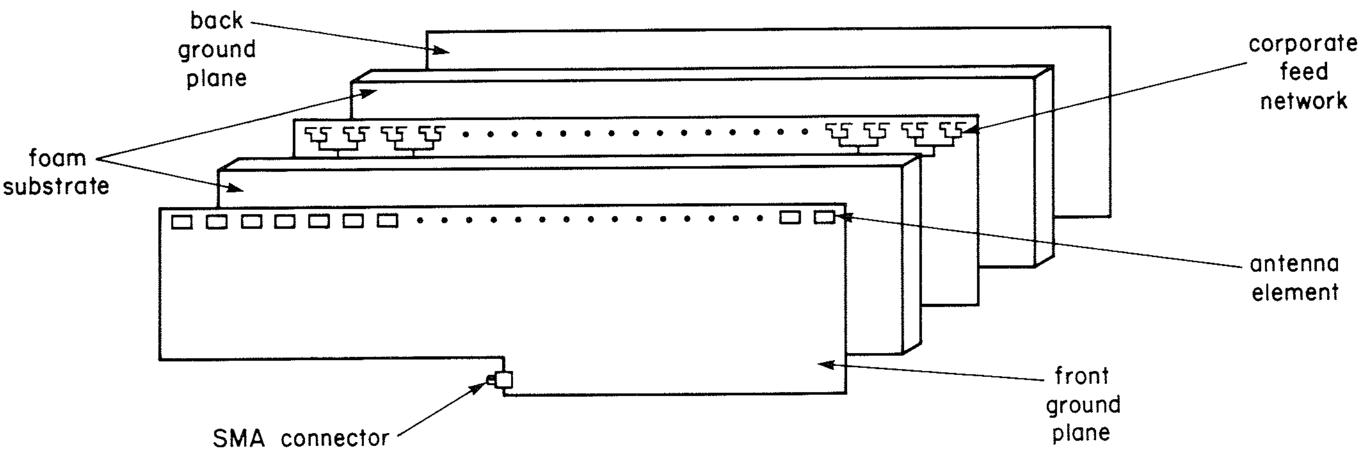

Fig. 5 - Exploded view of a 32-element sub-array.

tapers and hence different beam slew angles. In the case of this application, a fixed beam slew is added in the lines connecting the lens to the sub-arrays to produce a range of antenna beams on one side of broadside only.

In the original discussion it was noted that the beamforming could be achieved using a microwave lens with either a number of fixed beam ports or one adjustable one. It was decided to investigate the solution using a number of fixed ports, however this work could usefully be extended to examine the other option in a production design.

In Ref. 9 a number of designs of microwave lens was discussed and the most suitable was thought to be a Rotman lens. The advantage of a Rotman lens is that it has three perfect focal points rather than the two produced by the Ruze lens; this results in a lower phase error. A triplate construction technique was used in all the lenses examined in Ref. 9; microwave foam was used as the substrate material and microwave absorbing material was used either side of the lens to prevent internal reflections. The copper conductors were etched from a copper-clad polyimide film in a similar way to that used for the polariser and sub-arrays. This gave a relatively light, robust and low-cost construction.

A Rotman lens consisting of 7 beam ports and 24 array ports was constructed and reported in Ref. 9. A 50-array port microwave lens has been designed but not yet built because of a difficulty of getting sheets of copper-clad polyimide film of the required size; therefore the first stage of work was undertaken using the 24-array port lens. The effect of using the smaller lens is to reduce the gain of the array by around 3 dB and allow the beamwidth in the H-field plane to be twice as wide, apart from this the results should be directly comparable. The 24-port Rotman lens formed seven beams at slew angles of −24°, −16°, −8°, 0°, 8°, 16° and 24°. A fixed beam slew of 24° was added to produce a range of beams on one side of broadside only; these should be produced at 0°, 8°, 16°, 24°, 33°, 42° and 54°. The amplitude distribution across the array ports was found to be approximately co-sinusoidal as expected and a computer prediction of the patterns produced from the measured amplitude and phase distribution showed a first sidelobe level of around 20 dB below the main beam level.

The lens was measured[9] and found to have an insertion loss of 3 dB, which was higher than the 1.5 dB allowed for in the gain budget. This consisted of copper and dielectric losses in the lens, overspill of energy into the absorbing material at the side of the lens cavity and loss of energy into non-triplate modes. The latter effect is due to the asymmetrical nature of the triplate structure and should be reduced by producing a symmetrical structure with the triplate line etched on both sides of the polyimide film. This would also reduce the dielectric loss in the triplate which is substantially due to the polyimide film.

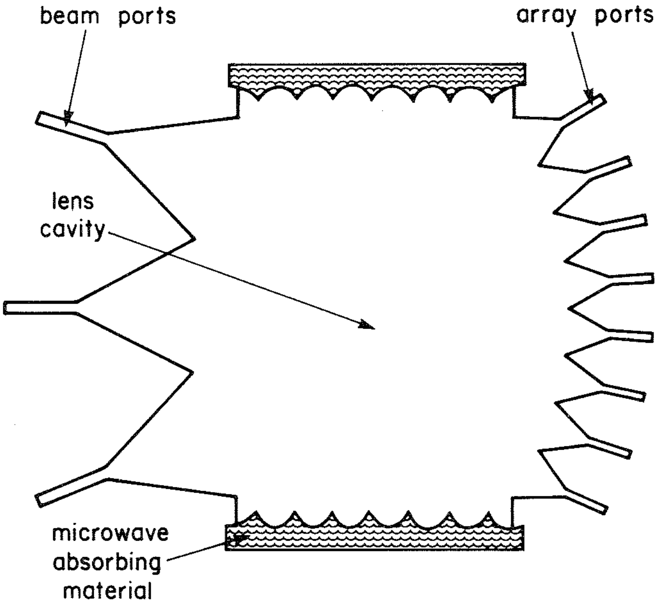

Fig. 6 - Diagrammatic view of a microwave lens.

4. INDIVIDUAL SUB-ARRAY PERFORMANCE

The performance of an individual 32-element sub-array when mounted in the stacked arrangement was measured. The co-polar and cross-polar radiation patterns were measured in the plane of the E-field and H-field. The results, Fig. 7, show a broadside co-polar pattern in the plane of the E-field with sidelobes around the −12 dB level, a slewed beam in the plane of the H-field with a slew angle of around 30° and a cross-polar discrimination of 20 dB. The main beam of the co-polar radiation pattern was found to be slightly more directional than expected from the results in Ref. 8. Therefore the element gain and hence the full array gain may be slightly reduced at large slew angles.

The boresight gain of an individual but stacked sub-array was measured and found to be 20 dBi. This is thought to be composed of 23 dBi of intrinsic antenna gain (an element efficiency of around 90%) with 2.5 dB of feed losses and 0.5 dB of mismatch losses. The level of the feed losses was slightly higher than expected. This was caused by the polyimide film both producing loss and causing an imbalance in the triplate structure so that other modes were excited in the triplate. As previously discussed, a possible solution is to print the feed structure on both sides of the film. If this were done the feed loss should be significantly reduced. The input impedance match was found to give a voltage reflection coefficient of better than 30% over the required band. Most of this mismatch was found to occur at the connector rather than at the elements or in the feed network. As a mass-produced antenna built using these principles would not have microwave connectors on each sub-array but would be connected to the lens using a triplate junction, this mismatch is not important. In general therefore the performance of an individual sub-array was found to be satisfactory for this application.

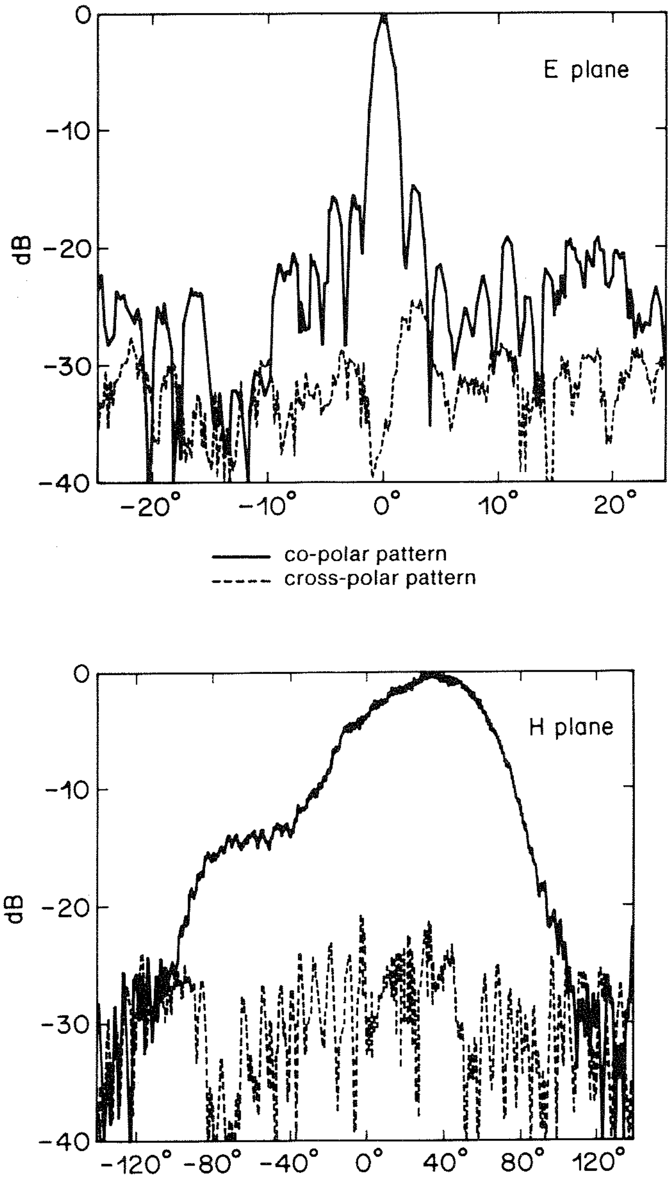

Fig. 7 - Radiation pattern of an individual sub-array in the E and H planes at 11.9 GHz (sub-array stacked in the proposed way).

—— co-polar pattern
----- cross-polar pattern

5. OVERALL ANTENNA PERFORMANCE

The polariser, sub-arrays and lens have been assembled and measured. The radiation patterns through each beam port of the lens have been measured in the H-plane of the array and are shown in Fig. 8, the measurements being made using a rotating linearly-polarised antenna. Fig. 8 shows that the beams have been formed in the expected directions. The last two ports show grating lobes. The lobe formed by the 42° port is reasonably well controlled. The largest slew angle of 54° is larger than would be required for this application; however in a final array a slightly closer element spacing would be necessary to reduce the grating lobe at these extreme slew angles.

The radiation patterns through each beam port were measured in the E-plane of the array. The results were, as expected, similar through each beam port and a typical result is shown in Fig. 9. The figure shows the narrow main beam with no slew in this plane, however the level of the first sidelobe on one side of the pattern has increased from the levels measured in the individual elements.

The gain of the array without the polariser was measured. The polariser was not included as the facilities for measuring the gain of circularly-polarised antennas were not available. The results, Fig. 10, show that a gain of between 27 dBi and 29 dBi was obtained between 11.1 GHz and 12 GHz from five of the beam ports. The gain of the antenna at the two most extreme slew angles was lower than this due to the combined effects of the grating lobes and loss of effective aperture. If the gain budget given in Appendix 2 is modified to allow for the aperture of this half-size antenna and the measured feed losses then the expected gain can be found to be 27.8 dBi; this, allowing for the experimental error of ±1 dB, agrees well with the measured result.

The axial ratio of the array with the polariser was measured on boresight. Fig. 11 shows the variation with frequency of the axial ratio of the broadside main beam. It can be seen that an axial ratio of better than 1.5 dB was achieved from 11.5 GHz to 12.4 GHz. The axial ratio is limited by the elements as the cross-polar discrimination was as good as was achieved by the array without the polariser when illuminated by linearly-polarised radiation. The boresight axial ratio was measured for various angles of beam slew at 11.9 GHz. The results, Fig. 12, show that an axial ratio of 1.5 dB was achieved out to a 45° slew angle. Beyond this angle the axial ratio was found to degrade swiftly. These results show that a satisfactory axial ratio and hence cross-polar discrimination can be obtained using this

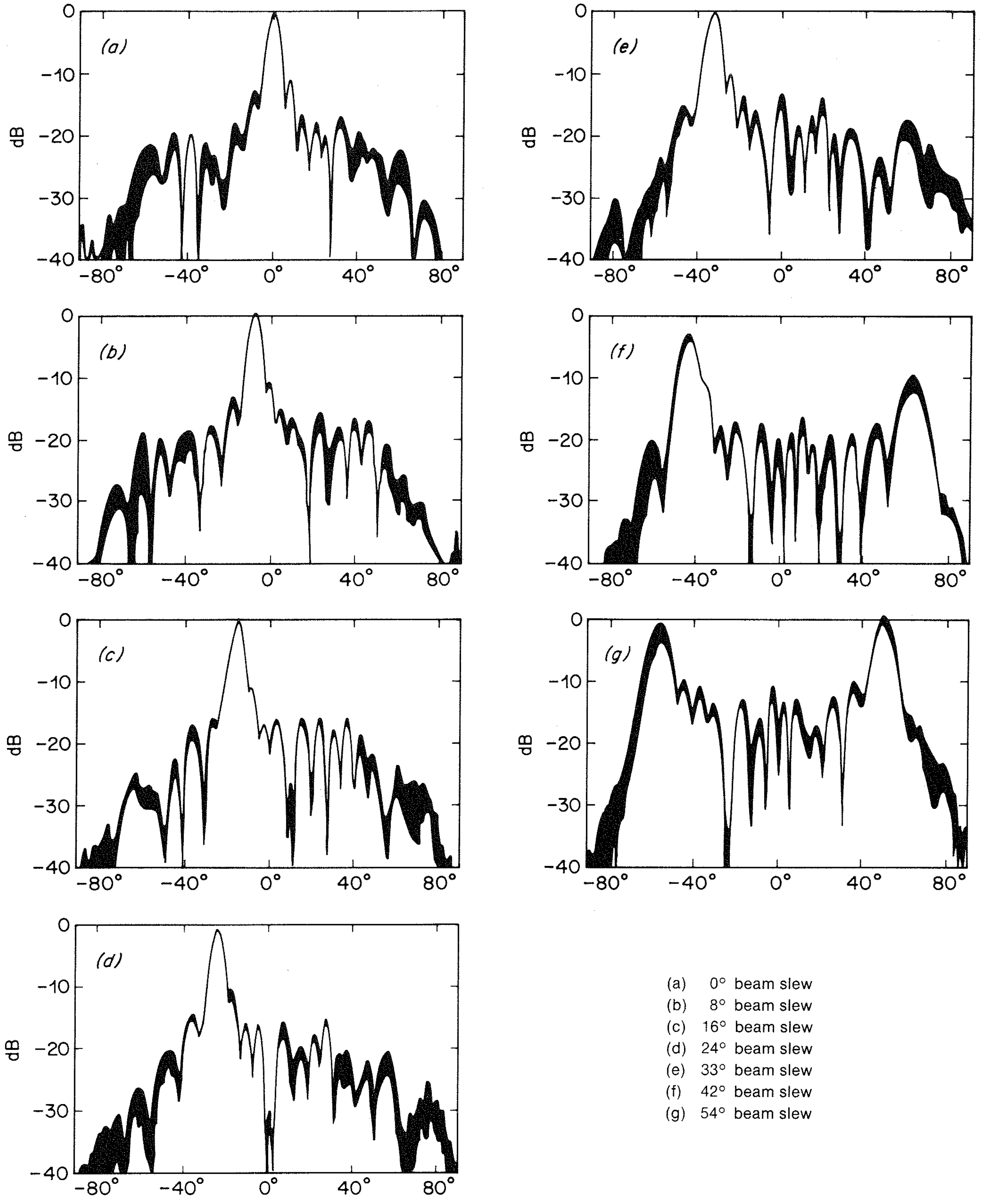

Fig. 8 - Radiation pattern of the array at each of the slew angles, measured in the H-plane of the array at 11.9 GHz using rotating linear polarisation.

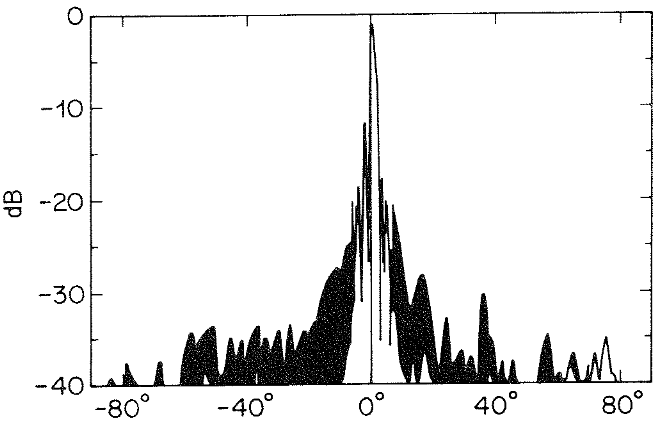

Fig. 9 - Radiation pattern of the array at the 16° slew angle, measured in the E-plane of the array at 11.9 GHz using rotating linear polarisation.

polariser over a wide range of frequencies and angles of beam slew. The measured performance was limited by the cross-polar discrimination of the array elements and structure rather than the polariser. The insertion loss of the polariser was measured and found to be around 0.5 dB, experimental error preventing a more accurate figure being measured.

These results demonstrate the feasibility of a flat-plate antenna for DBS reception. The gain of the antenna was slightly lower than expected; this was principally due to the feed and lens losses being slightly higher than expected. Both of these should be reduced by the use of a symmetrical triplate structure. It can be seen that an antenna with slightly reduced triplate losses incorporating a full 50-beam-port lens would give the required gain for DBS reception.

The 24-port lens, whilst not allowing a full-sized array to be used, performs satisfactorily and allowed the principles involved in the design of such a flat-plate antenna to be demonstrated. A 50-port lens would result in an extra 3 dB of antenna gain and if produced using a symmetrical triplate structure should have a similar insertion loss.

The overall antenna constructed was flat and less than 100 mm thick and hence can be termed a 'flat-plate' antenna. The antenna was built using low-cost materials such as copper-clad polyimide film, microwave foam and standard adhesive. The only relatively expensive materials used were microwave SMA connectors and microwave absorbing material, both of these could be replaced in a final design by either different construction techniques or different materials. The construction techniques used were also low-cost in that they involved printed-circuit board etching and laminating techniques.

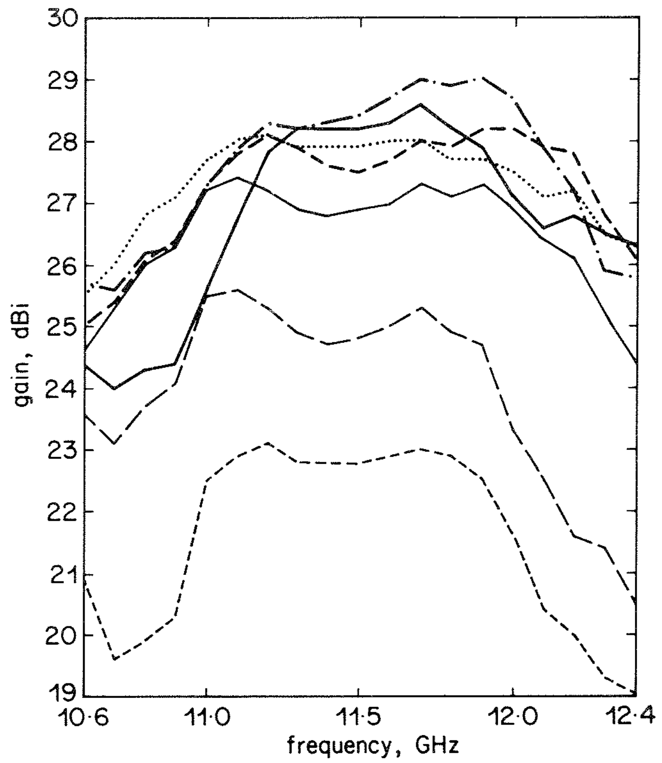

Fig. 10 - Gain of the array without polariser between 11.0 GHz and 12.4 GHz, at the various slew angles.

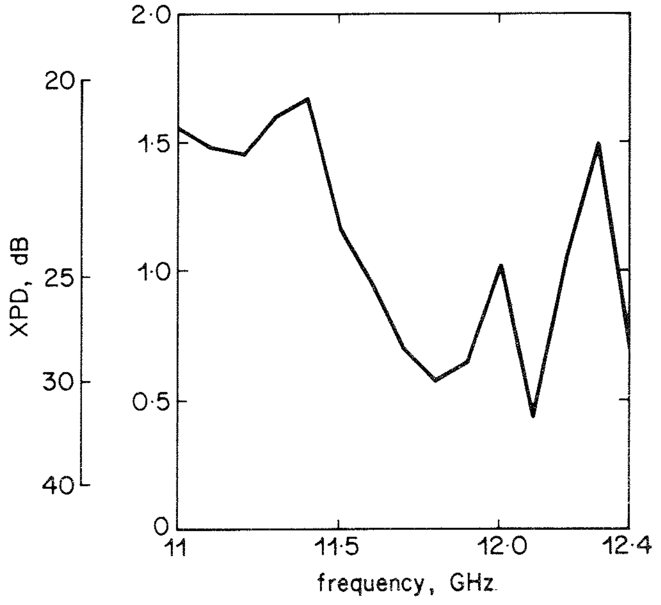

Fig. 11 - Broadside axial ratio of the array betwen 11.0 GHz and 12.4 GHz.

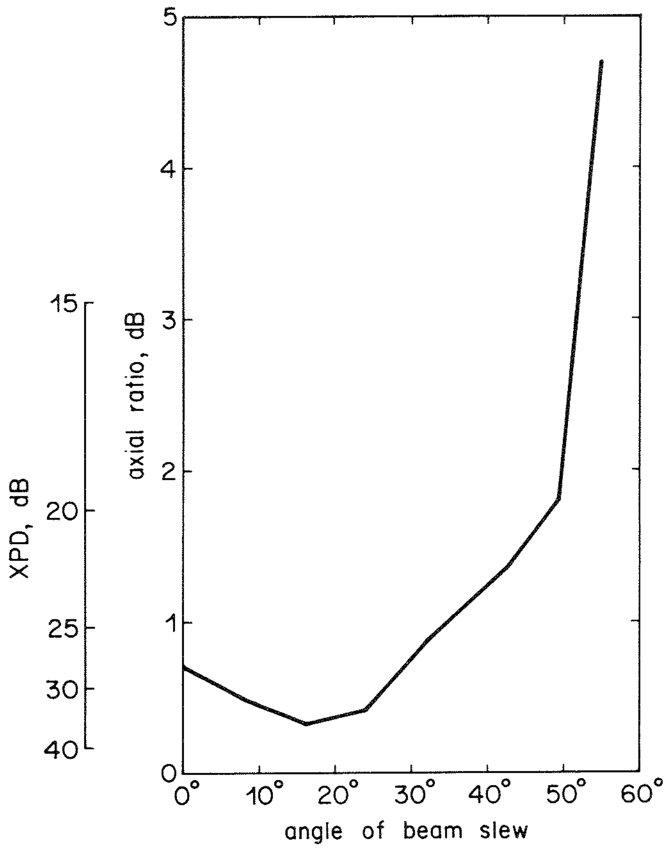

Fig. 12 - Axial ratio of the array at various slew angles from broadside, measured at 11.9 GHz.

6. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

A flat-plate antenna for DBS reception has been designed. The antenna was designed to be mounted flat on the most suitable wall of a house and can be aligned to receive signals from a DBS satellite. The antenna can be used on any house whatever its orientation providing an approximately south-westerly facing wall is available for mounting it. The antenna is steered by choosing the output port which gives the required slew angle and then rotating the antenna on the wall until the beam points at the satellite. A small mechanical adjustment can be used to fine tune the beam pointing if necessary.

A half-size antenna has been constructed from low-cost materials to demonstrate the design principles. The materials used are principally copper-clad polyimide film and microwave foam.

The demonstration antenna exhibits a boresight gain of 28 dBi and a cross-polar discrimination of better than 20 dB. It produces 7 slewed beams over the range of angles 0° to 54° on one side of broadside. At present a 24-port beamforming network is used and so 3 dB of extra gain should be achieved when a 50-port network is available and the full number of sub-arrays can be used. If the transmission line losses could be slightly reduced, the antenna would have the required gain for DBS reception.

There are two areas of work outstanding. The first would be to build a 50-port microwave lens so that the full antenna gain can be realised. The second would be to investigate various triplate constructions to reduce the triplate losses. This could considerably improve the antenna gain without increasing the antenna area. The antenna G/T could also be improved by incorporating low-noise amplifiers into the antenna on the outputs of each sub-array. This option will become more attractive as the domestic market for such amplifiers grows and their cost decreases.

As the BBC is no longer directly involved in DBS, little further work towards realising a commercially viable DBS flat-plate antenna can be recommended; however, the work described here could provide the basis for further development commercially. This design might be further refined to improve its electrical performance. Many of the techniques used in this work could be applied to the design of flat-plate SHF antennas for other applications of interest to the BBC, for example communications links.

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APPENDIX 1

Equations Relating to the 'Polar' Method of Beam Steering

To allow a flat-plate antenna to be mounted on the most suitable wall of an arbitrarily facing house requires the antenna beam to be steered with two degrees of freedom in order to point at the satellite. Conventionally a 'cartesian' solution is used and the antenna is adjusted in azimuth and elevation. It is proposed that a 'polar' approach be used as the range of angles over which the beam would need to be steered would be reduced. The equations for the 'polar' and 'cartesian' approaches to beam steering can be derived. Fig. A.1(a) shows an arbitrary point, P, which represents the position of the satellite. If a receiving antenna is placed at the origin of the axis then the elevation angle is, γ, and the azimuth angle, with respect to the y-axis, is δ.

If a flat-plate antenna is mounted on the most favourable wall of a house and steered using the 'cartesian' method then the situation is shown in Fig. A.1(b). The wall can be taken to be in the (x,z) plane without loss of generality. The required elevation and azimuth beam steering angle are given by α and β respectively and it can be shown that:

$$\tan\alpha = \tan\gamma \,/\, \cos\delta$$

and $$\beta = \delta$$

If it is steered using the 'polar' method then the situation is shown in Fig. A.1(c). θ is the beam steering angle of the antenna away from broadside and ϕ is the angle that the antenna must be rotated on the wall. It can be shown that:

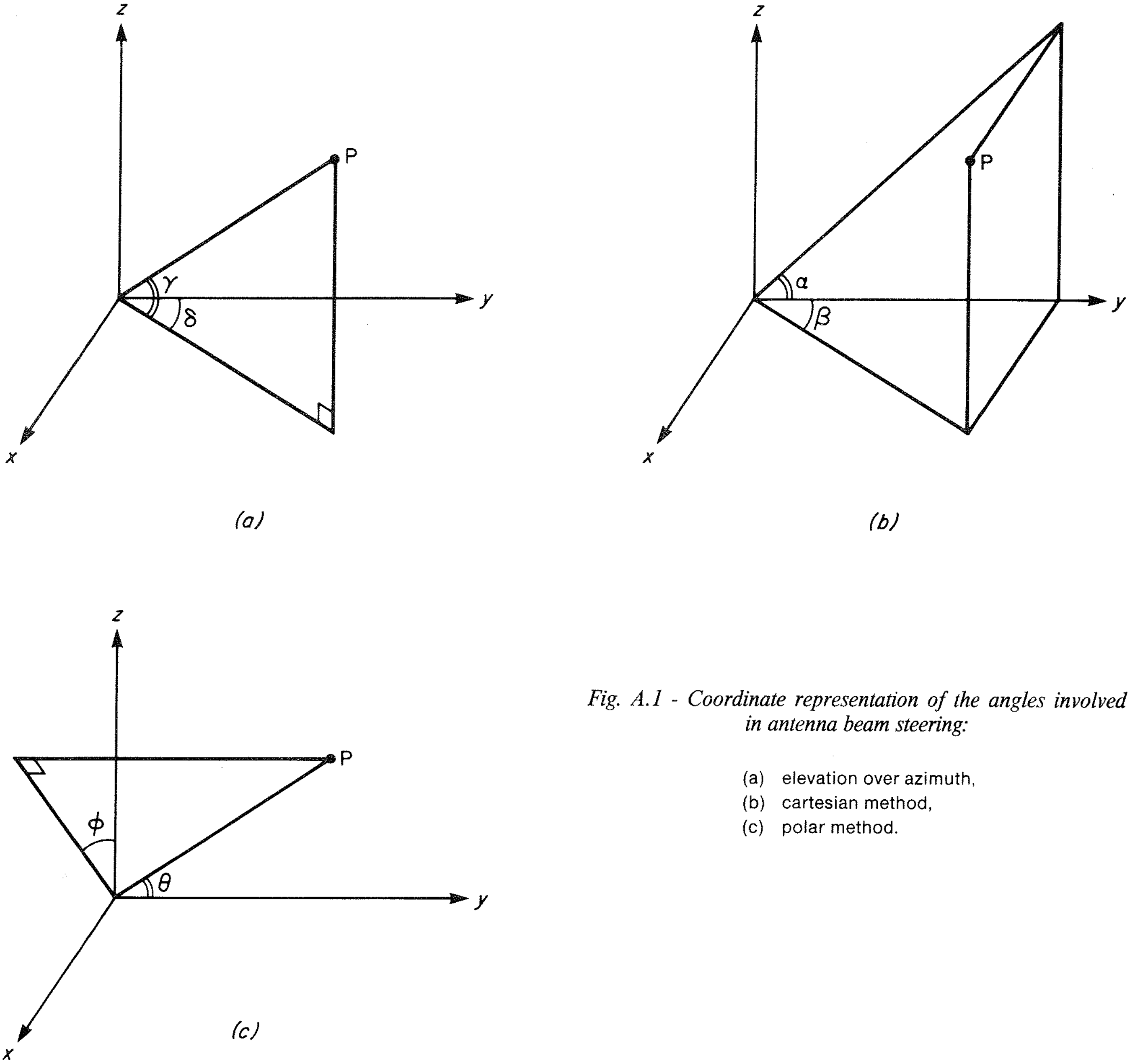
$$\cos\theta = \cos\delta \,.\, \cos\gamma$$

and $$\tan\phi = \sin\delta \,/\, \tan\gamma$$

The range of elevation angles required for reception in the United Kingdom of a satellite in the orbit position that would be occupied by a United Kingdom satellite is from 16° in the Shetland Islands to 29° in the Isles of Scilly. The range of azimuth angles required is −45° to +45°. In the polar approach any angle of rotation of the antenna on the wall is acceptable. The maximum and minimum values of antenna slew to accommodate any building in the country can now be calculated. The results are given in table A.1. It can be seen that a DBS flat-plate antenna steered using the polar method need only be steered over the range of angles 16° to 52° on one side of broadside. Using the cartesian approach the beam must be steered over −45° to +45° in azimuth and 16° to 38° in elevation.

Table A.1: Maximum and minimum slew angles required for DBS reception in the United Kingdom

	true azimuth (δ)	true elevation (γ)	Polar method	Cartesian method	
			antenna slew (θ)	azimuth slew (β)	elevation slew (α)
minimum	0°	16°	16°	0°	16°
maximum	+45°	29°	52°	+45°	38°



(a)

(b)

(c)

Fig. A.1 - Coordinate representation of the angles involved in antenna beam steering:

(a) elevation over azimuth,
(b) cartesian method,
(c) polar method.

APPENDIX 2

Target Antenna Gain and Loss Budget Calculation

To design an antenna for DBS reception it is necessary to predict the gain of the antenna and its losses so as to ensure that the required C/N is obtained for the specified percentage of time. In this Appendix the gain and C/N is calculated for the proposed antenna. The gain of an antenna is given by the equation:

$$\text{Gain(dBi)} = 10 \log [\, 4.\pi.A.\ \mu \,/\, \lambda^2 \,]$$

where: A is the antenna area
μ is the antenna efficiency
and λ is the free-space wavelength

To calculate the antenna efficiency a loss budget was drawn up; this can be divided into two sections, dissipative and non-dissipative loss.

Dissipative loss budget:

corporate feed structure: (including element efficiency)	1.5 dB	
triplate lens:	1.5 dB	
interconnecting cable:	0.5 dB	
polariser:	0.5 dB	Total: 4 dB

Non-dissipative loss budget:

loss of effective aperture:	1.9 dB	(for a 50° beam slew)
mismatches:	1.0 dB	
loss of aperture efficiency due to amplitude distribution across the array:	0.8 dB	Total: 3.7 dB

For the full antenna of area (covered by the elements) 750 mm by 760 mm the expected gain at 11.9 GHz can calculated as 32.8 dBi. A broadside beam would give nearly 2 dB more gain than this.

The G/T for the receiving installation using a full-sized antenna can now be calculated. Assuming a receiver noise figure of 3 dB, an antenna noise temperature of 150 K (which makes reasonable allowance for rain fading) the G/T can be found to be[3] 5.6 dB.

The carrier-to-noise ratio (C/N) can be found from the equation:

$$C/N = [\,(Po.\lambda^2\,)\,/\,(4.\pi.k.B)\,].\ G/T$$

where: Po is the power flux density,
k is Boltzmann's constant,
and B is the signal bandwidth.

The flux density at the edge of a WARC-77 service area is -103 dBW/m^2. The channel bandwidth is 27 MHz. At 11.9 GHz the equation reduces to:

$$C/N = G/T + 8.3\ \text{dB}$$

Therefore the C/N for the receiving installation can be found to be 13.9 dB. The WARC-77 standard[1] is that a C/N of 14 dB should be exceeded for all but 1% of the worst month. This antenna meets this condition for all but the worst case condition considered above; in that case it fails by just 0.1 dB. The condition considered is worst case because:

(a) it takes the edge of service area condition which is 3 dB lower than the beam centre flux density,

(b) it assumes a large angle of beam slew will be required with the consequent loss of effective aperture; most slew angles would give at least 1.5 dB more antenna gain.

An antenna meeting this specification provides the required C/N for the vast majority of cases and should be suitable for DBS reception.